DISCUSSION

RESERVOIRS[1]

By Dabney H. Maury

President Hill: We are very much indebted to Mr. Maury for this paper, because he has focussed attention on a very important principle of design which is frequently overlooked, that is, the great economies which may be effected by the proper location of a storage reservoir in conjunction with the distribution system. We are also indebted to him for the frank and fair way in which he has discussed all the difficulties which he has encountered in the construction of these reservoirs.

Mr. John C. Trautwine, Jr.: A philosopher has called attention to the beneficence of Providence in making its great rivers flow generally past our great cities. The same Providence seems to have surrounded Philadelphia with a rolling hill-country, with numerous tempting reservoir sites, with special reference to the city's needs in the matter of water supply.

From the beginning, in 1800, Philadelphia's public water supply was pumped from rivers to reservoirs, until, some fifteen years ago, the great Torresdale plant was installed, filtering the Delaware water there, and forcing it from Lardner's Point into the distribution by practically direct pumpage.

Mr. Maury has discussed the construction of reinforced concrete reservoirs. Philadelphia's first reservoirs were of reinforced wood. They were nearly cylindrical wooden vats, in the upper story of the tiny Centre Square repumping station, which occupied part of the present site of the City Hall. Their designers did not commit Mr. Maury's self-confessed mistake of putting the circumferential reinforcement on the inside. The bands were in the usual place.

But these first works, a sad abortion from the beginning, remained in operation hardly fifteen years, and they were then succeeded by the first, or steam, works at Fairmount, with their then world-

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renowned Fairmount reservoir, built immediately back of the pumping station upon a rocky hill which seems to have formed the site of one of Montresor's line of British fortifications This line stretched from river to river just north of what was then the northern limit of the city.

Beginning with Fairmount, the city has built a remarkable series of earthen reservoirs, on nearby eminences, gradually increasing in capacity, and culminating in the three large reservoirs: East Park, 1887-1889—689,000,000 gallons; Queen Lane, 1894—383,000,-000 gallons; Roxborough (new), 1893—147,000,000 gallons.

It will be seen at once that the dimensions of these reservoirs take them well out of the class discussed chiefly by Mr. Maury. Their history has been interesting, and, in a sense, pathetic.

East Park, a gigantic undertaking for its day, was long a-building, with protracted intervals of "nothing doing," and something of scandal. It seems now to be practically out of service, being filled with unused raw water.

Serious leakages from Queen Lane, when water was first turned in, afforded fine opportunity for the opposition press to belabor the administration; and Roxborough would doubtless have fared as ill, if its smaller size and its greater distance from the center of the city had not rendered it relatively inconspicuous.

Interior asphalt linings were promptly applied to both Queen Lane and New Roxborough reservoirs, and they have since been in full service without evidence of leakage; but at Queen Lane the south basin now acts as a settling basin, preliminary to filtration, while the north basin forms a filtered waterbasin for slow sand filters placed immediately over it; and at New Roxborough both basins serve as sedimentation basins for the nearby filters.

Thus, Philadelphia, once wholly committed to the use of large earthen reservoirs, for storage, now depends rather upon ample and modern pumpage capacity, drawing upon those unfailing sources of the raw material, the Delaware and Schuylkill rivers.

Mr. Alexander Potter: The author has very lucidly set forth the importance of the proper relative location of the service reservoir to the pumping station, and how large drafts upon the reservoir cause substantial drops in pressure in the case of an improperly located reservoir, while little or no drop occurs in case of a properly located reservoir.

This matter very logically has a very important bearing on the question of equitable insurance rates, but the speaker has yet to learn where the insurance companies have either given lower rates to the cities adopting the safe plan or penalized the city adopting the hazardous plan. The speaker's experience with the insurance companies would indicate that they would rather have a double pumping line to the city, which is more expensive and less serviceable, than a double supply, which is available in every city, where the service reservoir is on the opposite side of the center of consumption to the pumping station. The importance of this matter merits serious consideration.

Turning attention to the technical aspect of the paper, it can be safely stated that the economy and serviceability of reinforced concrete for reservoir construction are universally recognized, and engineering literature is replete with theories of design and construction. Nevertheless, very few of the reservoirs that have been built cannot now be improved upon. There is still room for progress in the art of designing such structures, and this can best be made by a careful study of all existing structures with special reference to the difficulties encountered in their construction and to the defects which have developed in such structures under service. The author, in giving his personal experience with the design and construction of some of the largest reinforced concrete reservoirs in this country, is adding a very valuable contribution to the design of reinforced concrete.

Most of the reservoirs described by the author are either built entirely below the surface of the ground or are surrounded by substantial earth embankments. Under these conditions the earth backing or embankments should be relied upon to resist a very large portion of the hydrostatic pressure. The concrete itself serves, to a very large extent, as a watertight lining. In such structures, as a rule, complete failure does not develop; partial failure, however, is quite common and is usually evidenced by considerable leakage. Such leakage is ordinarily readily remedied if it is due to defective workmanship, but cracks due to structural weakness, on the other hand, are frequently very difficult to make water tight.

The speaker agrees with the author that it is practical, with proper mixture and good workmanship, to obtain a concrete sufficiently water tight for reservoir purposes. In so far as materials

are concerned, the most important factors are sufficient cement and well graded sand. With the ordinary mixture of one part of cement, two parts of sand and four parts of broken stone, a concrete water tight for all practical purposes can be obtained if the sand contains the necessary amount of fine particles. With coarse sand it is advisable to add additional fine material to make a dense concrete. Hydrated lime ranging from 5 to 10 per cent of the weight of the cement used will give excellent results.

In thin sections concrete should be placed in layers not exceeding 8 or 10 feet in depth so that it can be readily worked around the reinforcing bars and spaded in the vicinity of the forms.

Another important factor, and one very often neglected, is the shape of the steel used for reinforcing. Round bars, or bars approximately of circular shape, are to be preferred. Square bars more than one inch thick should not be used at all in a wall section, for with such large size bars it is very difficult to get the concrete to flow into and fill the space just below the bar.

The author appears to have used structural channels extensively in connection with reservoir work. The speaker questions this practice, for the following reasons:

First. Structural channels used in thin wall sections tend to weaken the tensile strength of the concrete by breaking up its continuity.

Second. With such large sections it is very difficult to completely fill with concrete the space underneath the horizontal rods adjacent to the channels.

Third. The same amount of vertical steel more evenly distributed in small sections around the perimeter of the reservoir would give more satisfactory results, for vertical reinforcement is not only needed to hold the horizontal bars in alignment during construction, but a certain amount of vertical steel properly distributed is necessary to resist the vertical secondary stresses developed in this type of reservoir wall.

The disadvantages just enumerated more than balance, in the speaker's opinion, the advantage of simplicity of erection and the positive spacing secured by the use of structural steel channels.

In building concrete reservoirs in which the hydrostatic pressure is resisted by ring tension, the grave mistake is sometimes made of placing the steel too near to the inner surface, which results in the development of secondary stresses of considerable magnitude.

Theoretically, in a thick, hollow cylinder, the tension is a maximum at the inside surface, but this is not the proper location for the reinforcing bars in a reinforced concrete circular reservoir. If only one set of circumferential bars is used these should be placed nearer to the outside surface than the inside. The most economical arrangement in wall sections 12 inches or more in thickness is in using two concentric rings of reinforcing bars, one placed within 2 inches of the outside surface and the other within about 3 or 4 inches of the inside surface. Such a distribution is very effective in resisting not only the hydrostatic pressure but in resisting whatever secondary stresses may be developed in the shell from any one of a number of causes. With the reinforcing steel placed too close to the inner surface the concrete at the outer surface is frequently overstressed, resulting in partial failure and a leaky reservoir which it will be most difficult to make water tight.

The speaker sees no reason why the use of chutes for conveying concrete should not be permitted provided concrete is not allowed to flow along the forms but is pushed laterally by means of a hoe or some other suitable instrument, at the same time working the material to a proper consistency.

The defects developed in the concrete lining of the new 4,000,000 gallon reservoir illustrated in figures 13 and 14, are not in the speaker's opinion due primarily to the use of the water proofing compound. He is rather inclined to believe that in placing the concrete the contractor permitted a rather wet mixture of concrete to flow laterally along the forms. This resulted in a partial separation of the cement, sand and stone. The cement which accumulated in pools of water resulted in the formation of laitance. This laitance when set possesses a creamy or yellow color and can be freely carved with a knife, its consistency being that of clay, only very porous. The speaker recalls an instance where, in building a series of reinforced concrete arches, the cement mortar collected in pools at the springing line of one of the arches, resulting in the material possessing the same properties as those mentioned by the author. No waterproofing compound was used in this instance.

The waterproofing compound in the instance of the 4,000,000 gallon reservoir, though not a direct cause, in all probability aggravated the formation of the objectionable substances referred to by the author.

Contrary to usual opinion, leakage at construction joints, pro-

vided proper precautions are taken, is never serious, and such leakage can be practically entirely avoided by the use of sufficient steel tying the sections together or by the construction of a water tight expansion joint. In bonding new concrete to that which is set the connection surface should be fairly rough and clean. The practice, after the concrete has set, of roughing the surface with picks or chisels should be condemned, for the effect of the blows of the chisel or pick penetrates the mass to a considerable distance, especially when the concrete is comparatively clean, leaving the aggregate below the construction plane loose, through which leakage may later take place. A good watertight bond can be secured by spreading upon the connecting surface immediately before concreting a ½ inch layer of semiliquid cement mortar. This mortar should be thoroughly brushed into all crevices and worked back and forth over the surface so as to assure a good bond to the concrete mass, otherwise a film of dust or dirt might prevent proper adhesion. The use of a vacuum cleaner, as suggested by the author, should be of value in removing dust and rubbish from narrow sections difficult to get at.

The pouring of grout between the forms and the concrete backing, as followed in the construction of the 10,000,000 gallon reservoir at Bloomington, Illinois, is a refinement not necessary to secure satisfactory results, and to the speaker's knowledge is no longer generally used. This method, although it gives good results, is very costly and is not without its drawbacks, for when the sheet metal forms are left in too long the mortar lining does not properly bond to the body of the concrete, and when set, sounds hollow under the blow of a hammer. This is especially the case when a richer mixture is used in the mortar lining than in the body of the concrete.

Mr. W. F. Wilcox: Are not the channels criticised by Mr. Potter intended to keep the reinforcing in place and not to increase the strength? Of course we all know that the distribution of the steel in the horizontal layers would add more to the strength; but in looking over Mr. Maury's design the speaker did not understand that he undertook to increase the strength of the reservoir.

Mr. Dabney H. Maury: Perhaps Mr. Wilcox did not understand quite clearly the reference in the paper to channels. The

channels were used not without consideration of the points raised by Mr. Potter; but they were used as a choice between several things which might have been done. They seemed to offer structurally the most convenient method of placing and holding in place the steel which has to be bolted or tied to something in the practical work of constructing the reservoir. They were not inserted for their reinforcing value, for while they might help a little in preventing horizontal cracks, their usefulness in this respect would be negligible, as the upper end of the wall is free to move, and vertical temperature steel would therefore be unnecessary.

The supposed danger of cracking that might result from the insertion of these channels, which would occupy only a very small percentage of the cross-sectional area of the wall, was not actually present, because in the design of the walls the tensile strength of the concrete was in no case relied upon, the stresses in the steel being kept low enough to prevent vertical cracks. No vertical cracks could be found with a magnifying glass in any of the reservoir walls at any time, either near the channels or anywhere else, except the entirely harmless cracks on the outside of the bottom of the 4,000,000 gallon reservoir, which cracks were fully described in the paper and which, as therein stated, were due to the author's overlooking the precaution referred to by Mr. Potter, and failing to put a part of the reinforcing steel near the outer edge of the wall.

It would have been manifestly unsafe to rely on the earth pressures because in very dry or very cold weather it might readily happen that the earth would shrink away from the outside of the wall of the reservoir to such an extent that the internal pressures might, if the wall were not strong enough to resist them unaided, set up disastrous cracks in the wall before the wall had stretched enough to come into bearing against the outside earth. The foregoing remarks apply with full force to all of those reservoirs in which the pressures were resisted by steel placed hoop-fashion in the wall.

In the design of the 7,500,000 gallon reservoir, that portion of the wall which rested against solid rock had no horizontal reinforcement, but was simply a lining placed against the rock, the rock being relied upon to take all of the stresses. In that portion of the wall which extended above the rock, and most of which was surrounded by earth, no reliance was placed on the outside earth for the reason already given, namely, that the wall at some time might have yielded to the breaking point before it could come into bearing against the earth.

In the design of the 1,200,000 gallon covered reservoir no reliance was placed on the earth pressures for similar reasons. The design of this reservoir involved much study of the best method of holding the bottom of the wall, not only against internal water pressures, but against the thrust of the inverted groined arches. This could have been accomplished by putting reinforcing steel all over the bottom to take care of the thrust; but had this been done there would have been no economy in using the inverted groined arch, a type of bottom which was peculiarly well suited to the local conditions, not only because of the loads which will later have to be carried by the columns, but also because of the possibility of trouble on account of high ground water during construction.

The next alternative which presented itself for taking care of the combined thrusts of the water and of the arches was the construction of a massive gravity-section retaining wall around the reservoir, the weight of which would be so great that friction alone would prevent its starting to move. Such a wall would, however, have added greatly to the cost, and the advantage that might have been gained by utilizing the tensile strength of the bars in the roof slabs to hold the top of the wall in place would practically have been wasted.

It was finally decided to make the outermost bay, on each of the four sides of the reservoir, of reinforced concrete so designed that its weight, plus the weight of its contained water, would provide sufficient friction to prevent its starting to move outward, even when impelled by the water pressures as well as by the thrust of the arches. This same outer bay would also have, when the reservoir is empty, sufficient weight to produce friction that would enable it to resist, without moving, the thrust of the groined arches. The space inside of the bay is of course useful for the storage of water.

These explanations will, it is thought, make it clear why it would have been unwise in any of the designs referred to, to place any reliance on the pressures of the outside earth.

Mr. W. F. Wilcox: You have answered the question the way the speaker wanted you to answer it. You have explained that according to his own idea or conception of designing a reservoir, he having designed and built several reservoirs. With the first

one built there was a very unfortunate experience, some reliance was put on a bank of earth, it was built on the seashore where there was running sand. Some time after it was built the municipal authorities removed the embankment from the outside of the reservoir and dug underneath the reservoir to see if there was any leak in the bottom. They were very much surprised that the reservoir cracked, and called the speaker in a hurry and asked him why it cracked? The polite answer was that it was not "fool proof."

Some years ago the speaker built a 20,000,000 gallon reservoir with a heavy embankment and heavy excavations. The embankment was built in six inch layers, carefully watered and carefully rolled. It was found that it was impossible to roll the outside edge of the embankment; therefore, after the reservoir field had been ploughed according to the plans, the inside surface was dressed down until it was firm and compact The lines of the design were changed so as to put in a concrete lining on a firm bank. The edges of the applied squares were painted with ordinary paving pitch, and then alternate squares were put in. In putting these squares together a circle 6 inches in width and 3 inches deep was left. This was then carefully painted with paving pitch, and the filler concrete put in. No leaks have been found in it. It was a very cheap method of construction and has given very satisfactory results. The entire work was completed in fifty-seven days.

In a vertical thin wall reservoir the speaker uses two lines of steel, putting sufficient steel in to take care of all the stresses, not depending upon the concrete for any stress. He built a reservoir 100 feet square, 20 feet deep, using ordinary steel plates 12 inches wide, and hot paving pitch to make the expansion joints. The width of the buttresses on the outside was doubled, one-half of the buttress being put up when the first section was put up, and when the plate was inserted sticking out 6 inches. That reservoir has been up ten years and has never leaked. In the construction of a dam where there was 80 feet of water, paving pitch was used, making a number of applications of the pitch, drying between coats, until it became a quarter of an inch thick. Three foot observation holes were left, and men sent down into those holes for the past five years have found that they held.

In regard to changing mixtures and adding hydrated lime, a mixture of one, two, four with properly selected material properly placed will make a reservoir practically tight. There will be in

the construction some weak places which will develop but those can be readily cut out and doctored. The leakage will be very small.

The speaker does not think it well to use any plaster on the inside of the wall. It might be advisable under certain conditions to use some waterproofing material. That is entirely within the judgment of the engineer. If you will use in an ordinary settling basin a small percentage of alum, the sedimentation in water will finally take up the leaks and bring about satisfactory results.

Mr. Dabney H. Maury: Mr. Potter's recommendation that in roughening the surface of the completed work before pouring new concrete on top of it, there should be no jarring or chipping, is a wise one. The author's specifications in regard to that provide that the roughening of the surface should be limited to scratching it.

Mr. Potter's suggestion in regard to the use of round rods was also a very good one. Round rods have another advantage on which Mr. Potter did not touch, and that is that they bend much better than square or deformed rods. If you undertake to bend a square rod it is very hard to make it stay in the same plane. In bending a round rod there is no tendency for the rod to get out of the same plane, and this is a decided advantage.

With regard to the mortar forms Mr. Potter has suggested quite properly a number of precautions that should be taken. Those precautions had not been overlooked, and are all included in the specifications for the last reservoir for which the author prepared plans, and in which the use of these forms was required. It is true that if not used properly there may not be a good junction between the mortar facing and the concrete back of it. Used properly, these forms serve an excellent purpose by insuring that no stone shall rest against the inner face of the forms. In any event their use conduces to a care on the part of the contractor and of the inspectors that probably would not be secured by simply specifying, as is usually done, that the contractor shall spade the concrete thoroughly next to the forms. There is something definite there that the inspector will be watching all the time, and in a general way they thus conduce to the care with which the construction is carried out. Careful estimates of the additional cost of these forms were made, and this cost was found to be lower than the value of the advan-

tages that would result from their use. There might of course be cases in which the estimates would give contrary results; but when the advantages are considered and weighed against the cost, the author believes that in many instances it will be found good practice to use the mortar forms.

Mr. Alexander Potter: With reference to the exceedingly low amount paid to the contractor for the Bloomington reservoir, $35,000, it seems out of proportion to the actual cost. Can the author tell us what were the conditions that caused the contractor to accept so low a price? What proportion of the saving on the other work undertaken by him can be properly charged to the reservoir? The price is so very low for a reservoir of this capacity that it seems hardly a fair figure to give as representing the cost.

Mr. Dabney H. Maury: That is quite a proper question. The contractor's original bid was $37,500. If the work had been awarded to him on his original bid he would probably have made about $2,500 profit. The actual cost to him was, as nearly as it could be figured, $35,000. That allowed him nothing for his own time, and nothing for his partner's. They stayed on the work, dividing the time between them, day and night. They got nothing for their own services and nothing for depreciation on their tools, or plant. Prices at the time were fairly low. They were not as low as they have been in the last two or three years preceding the recent sudden rise due to the war, but they were lower than the average prices. The author believes that the excellent results were accomplished largely by the earnest and conscientious work of the contractor. The author had nothing to do with the supervision of the work, but was simply employed to make the plans and specifications, and can claim no credit for anything else.

Mr. Alexander Potter: The speaker would appreciate it if the author could include the unit prices of the work, because, compared with works with which he is more familiar, the cost of the Bloomington reservoir seems so very low. The unit prices would be interesting for comparison.

Mr. Dabney H. Maury: The author would be glad to do that if he could. The reservoir is, however, an old one, built about

eleven years ago at Bloomington, Illinois. The contracting firm that built it has gone out of business, and the unit prices would probably be hard to obtain. The author took at the time the contractor's own figures of his costs, but not in any very great detail. The author knew the amount of the bid, and the amount which the contractor said he made, which was nothing. The author thoroughly believed him. Of course, in considering the costs of that reservoir one should bear in mind the fact that it is a large reservoir; and while $3,500 per 1,000,000 gallons capacity is probably the record for a reinforced concrete reservoir involving so much excavation, the same type of reservoir, if of only 5,000,000 gallons capacity, would have probably cost $5,000 or $6,000 per 1,000, 000 gallons. There were no unusual difficulties encountered. The excavation was clay for the top soil, with bottom soil of sand and gravel, all which could be handled very easily. The contractor used good construction methods; he and his partner stayed there day and night, and they completed that work in one hundred days.

The details of the construction of that reservoir were quite fully described in *Engineering Record*, of March 3, 1906, in an article written by Mr. S. T. Henry, of the editorial staff of the *Record* at that time, who obtained many of the construction details from the contractor.